

# **Evaluation of the Effects of Distributed Roughness Induced Transition on the EXPERT Vehicle**

**International Planetary Probe Workshop 2010 (IPPW7)**

**Barcelona, Spain**

**14<sup>th</sup> - 18<sup>th</sup> June, 2010**

**Guillaume Grossir, Sébastien Paris, Olivier Chazot**

**Von Karman Institute, Belgium**

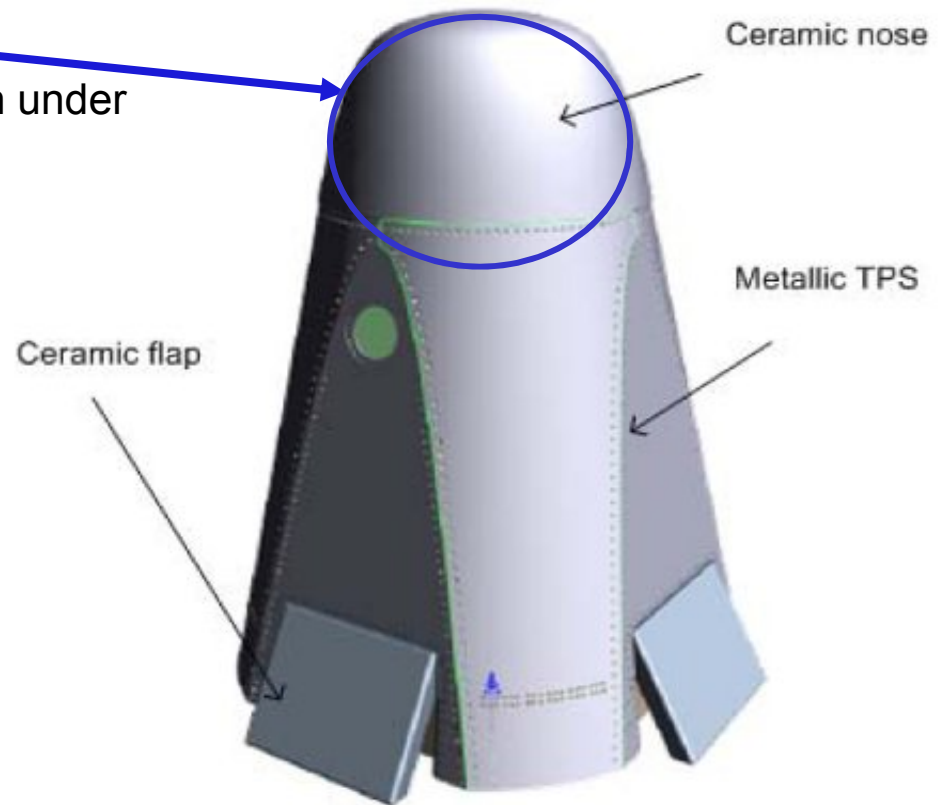
# Distributed roughness

Nose of the Expert vehicle in CSiC

Active oxidation of the material can happen under specific condition:

↳ Distributed roughness on the nose  
Turbulent flow

- Turbulent flow over the model can produce critical heat flux.
- Damage of the vehicle
- Payloads installed on the model can not be processed



What is the maximum allowable height for the roughness without triggering transition?

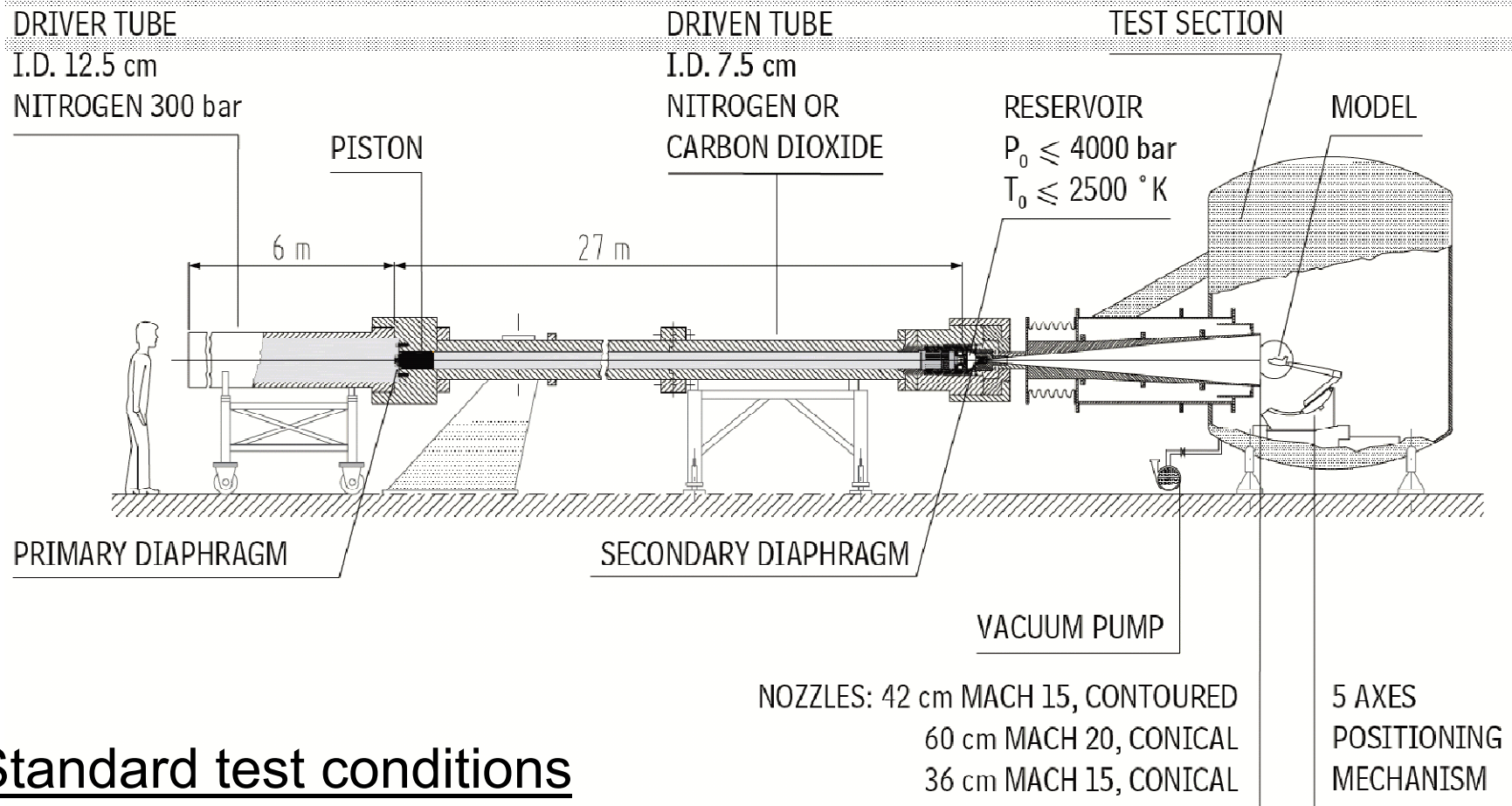


# Methodology

- Tests in the Longshot facility,
  - Extraction of heat flux and Stanton number for qualification of the flow (laminar or turbulent)
- Evaluation of empirical correlations to predict transition,
  - Reda,
  - Reshotko,
- Comparison of experimental data and correlations
- Extrapolation to flight



# Longshot facility

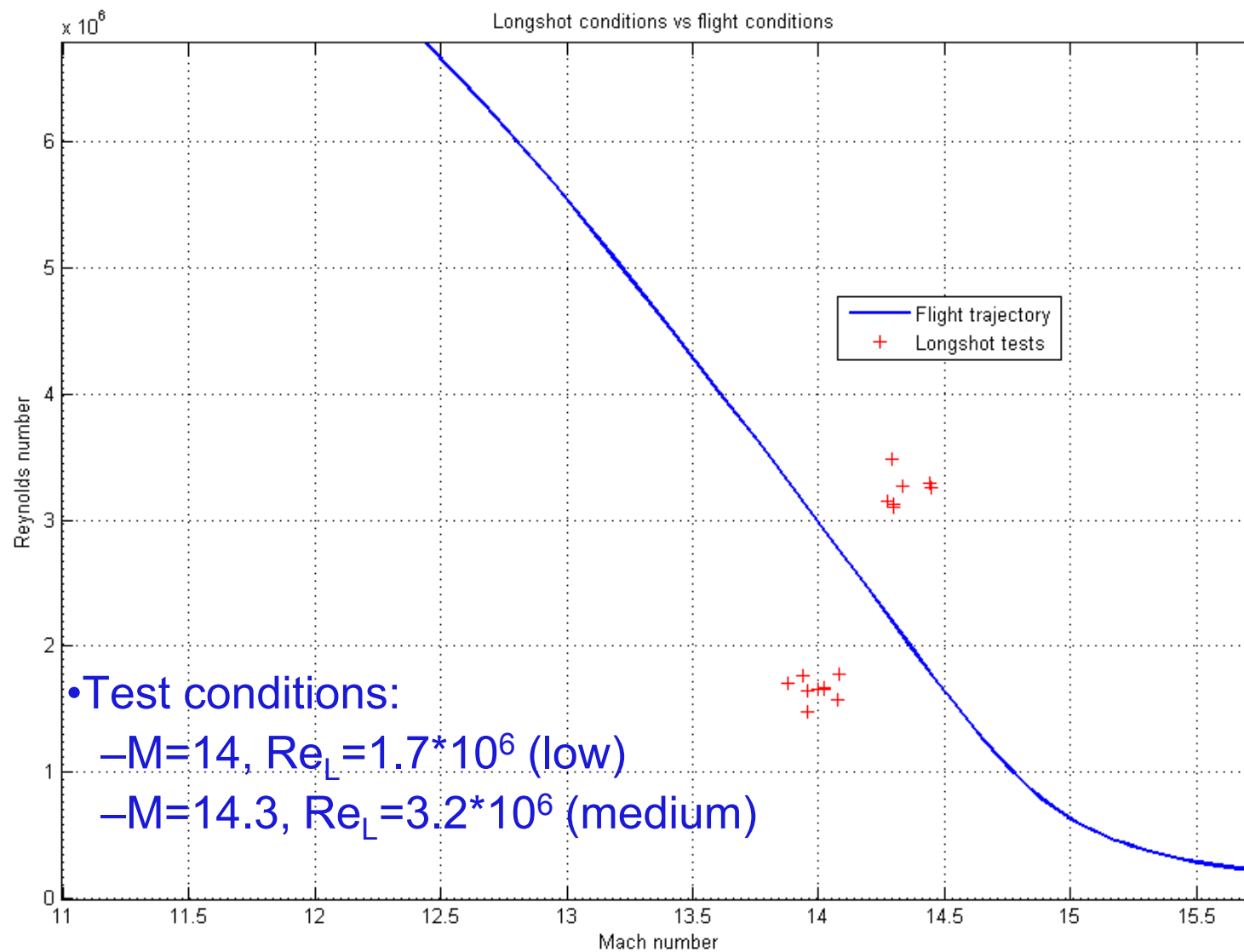


## Standard test conditions

Condition	Gas	$T_0$	$P_0$	Mach	$\rho_\infty$	$U_\infty$	$P_\infty$	$T_\infty$	Unit Re
		[K]	[bar]	[-]	[kg/m <sup>3</sup> ]	[m/s]	[Pa]	[K]	[-]
low Re	N <sub>2</sub>	1740	550	13.9	0.0108	1880	140	44	6
med Re	N <sub>2</sub>	1640	1100	14.3	0.0196	1820	225	39	13.2
high Re	N <sub>2</sub>	1745	1470	14.8	0.0206	1880	235	39	17.5

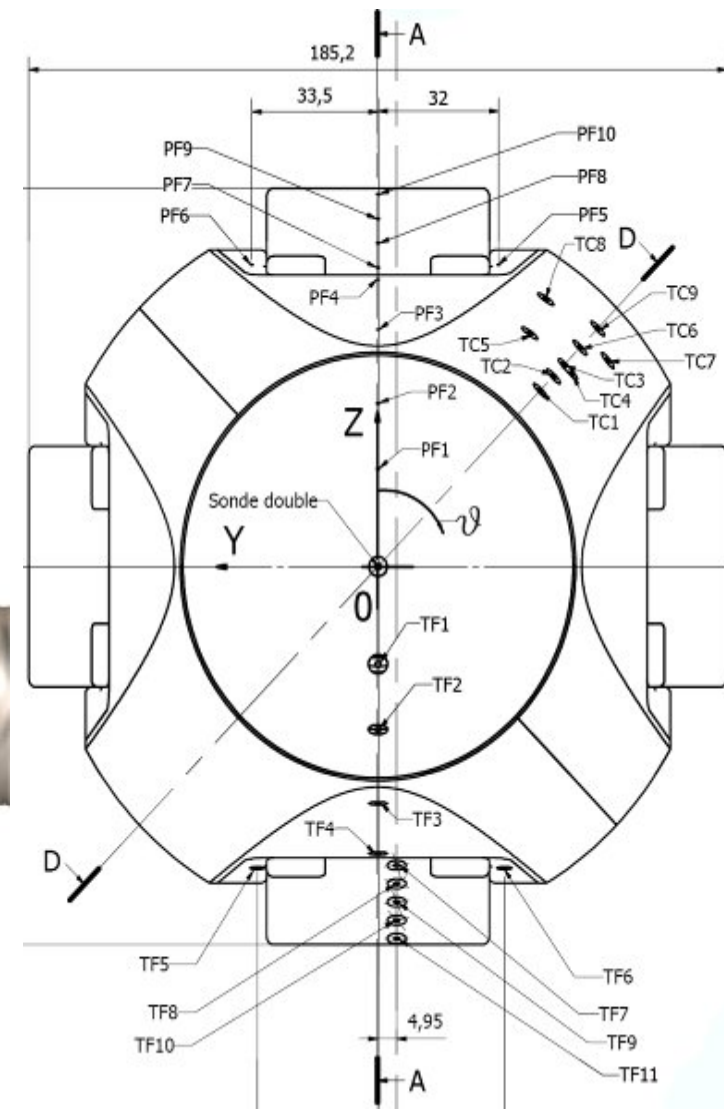


# Longshot facility



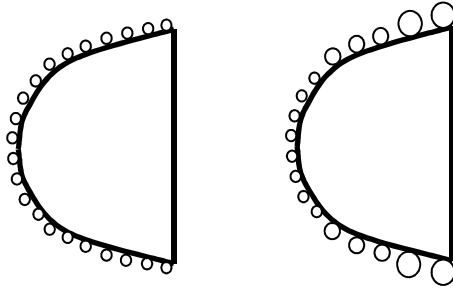
# Expert model

- 23cm long,
- 21 thermocouples,
- 11 pressure sensors.



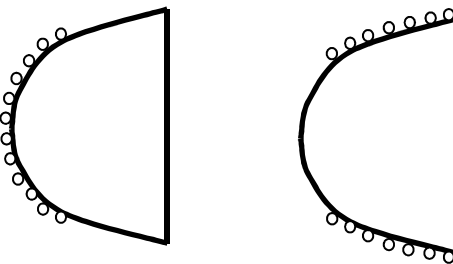
# Distributed roughness

- How do we represent roughness on the nose?



- Does oxidation occur everywhere on the nose?  
→ **roughness location on the nose**

- How does roughness develop itself along the surface?  
Main unknown,  
→ **identical size along the nose**



- Is there a **location** more important than others?  
→ **tests with roughness only on the first part of the nose.**
- Does **density** of distributed roughness have an effect?  
→ **tests with various density of roughness on the nose.**

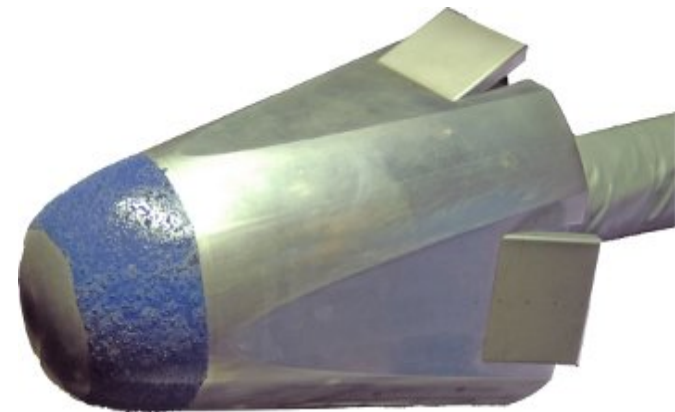
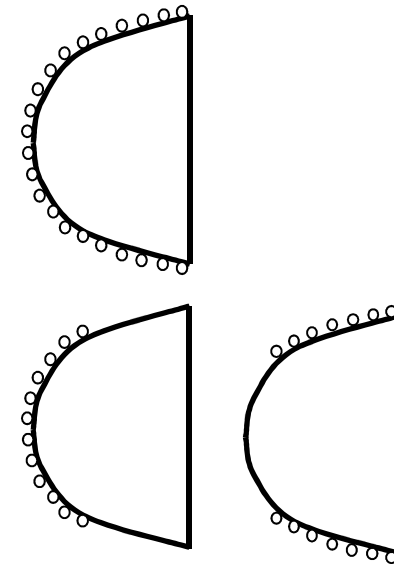
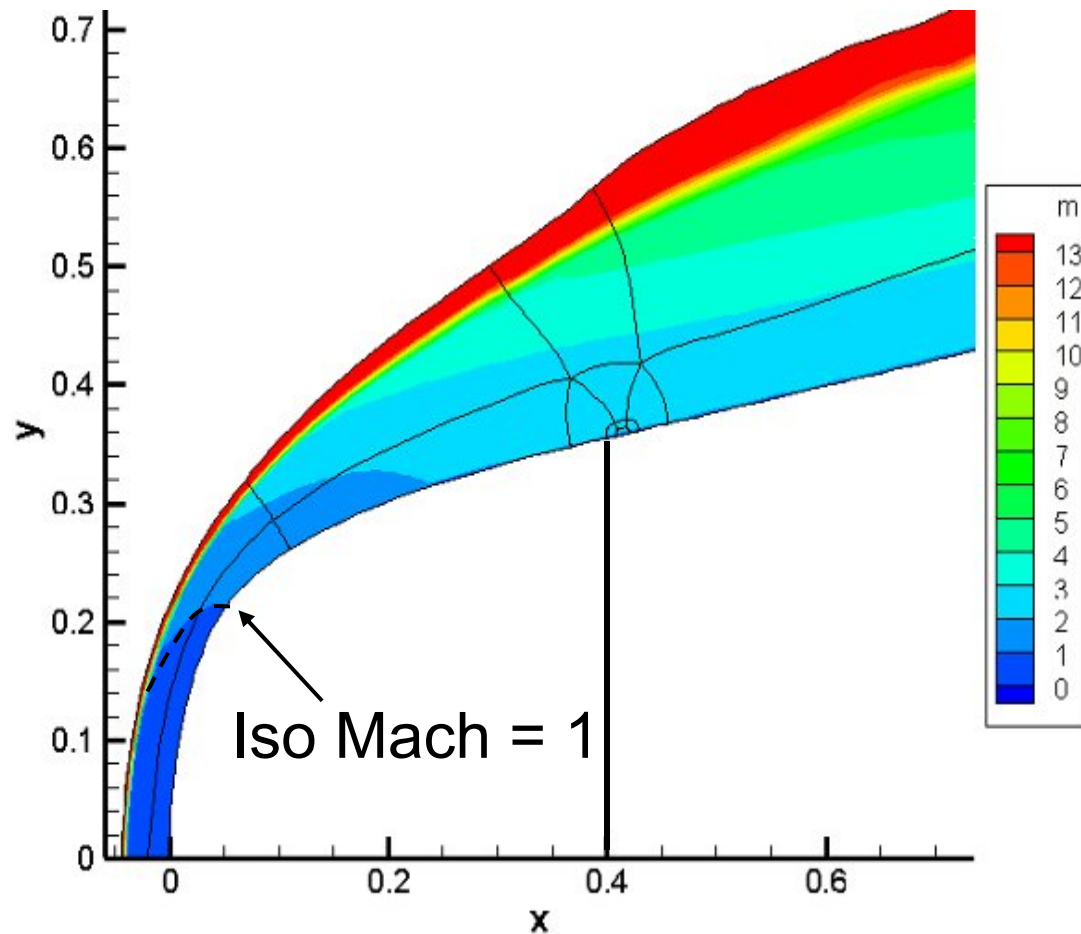
## Test Matrix

- **Smooth** reference cases : 2 tests (for low and medium Reynolds number).
- **Location** of distributed roughness effects : 3 tests.
- **Density** of distributed roughness effects : 3 tests.
- **Size** of distributed roughness effects : 6 tests at low and medium Reynolds number.



# Longshot Experiments, effects of roughness location

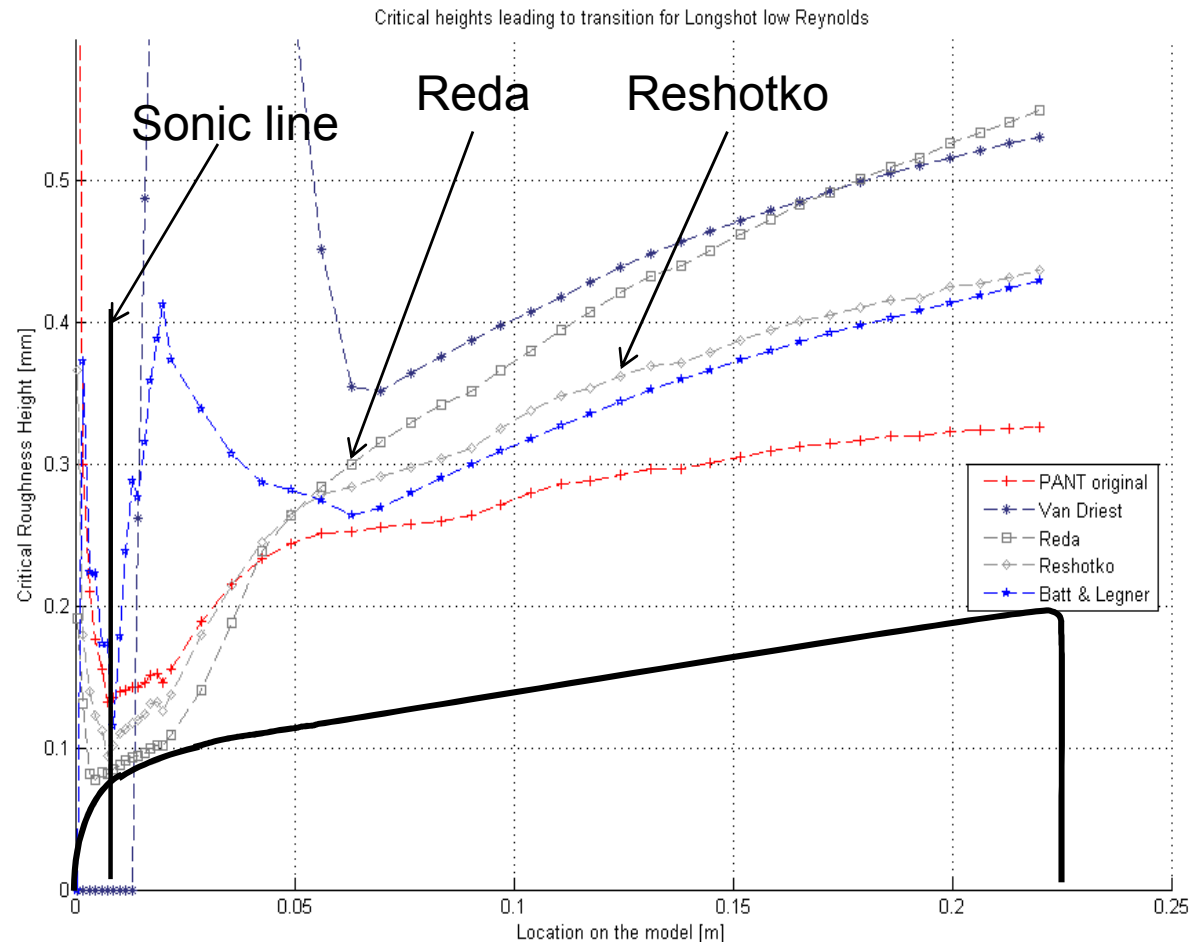
“Which zone of the nose is the most likely to trigger transition?”



# Effects of roughness location

- Empirical correlations to predict transition on the EXPERT model

Only **Reda** and **Reshotko** criteria can be applied to distributed roughness



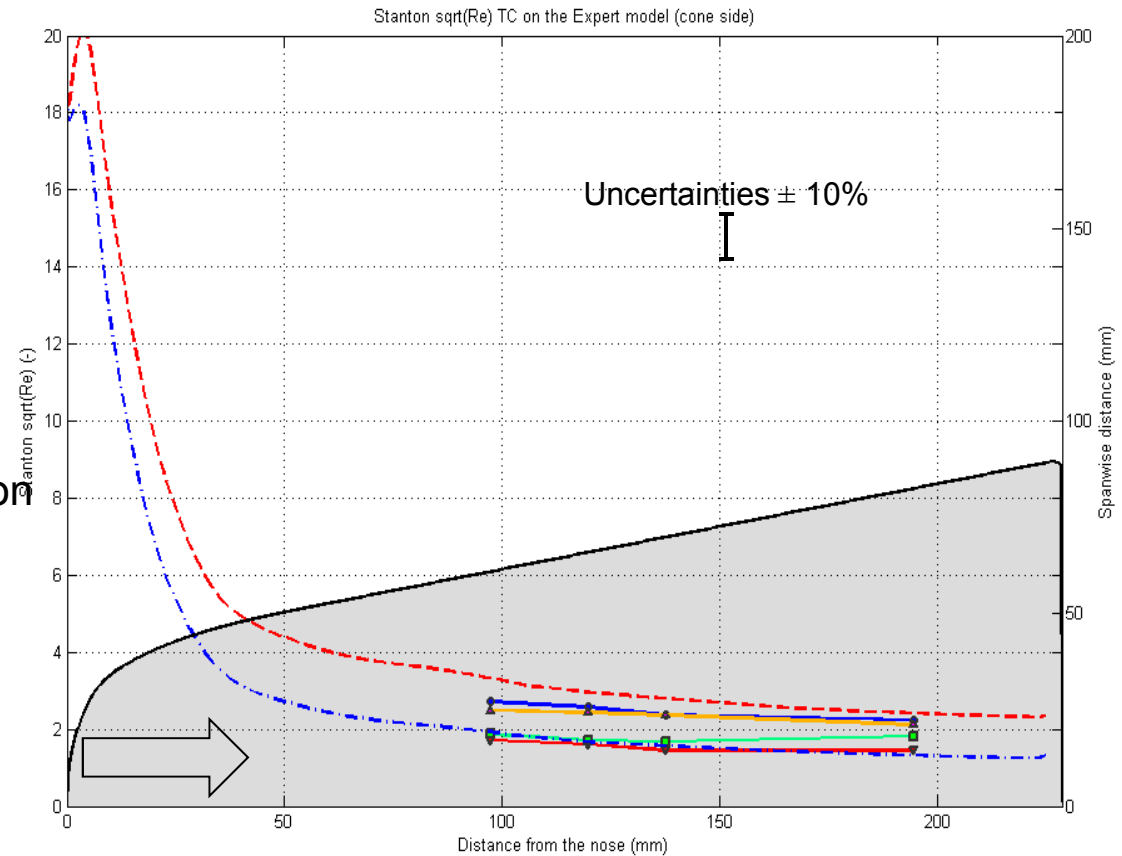
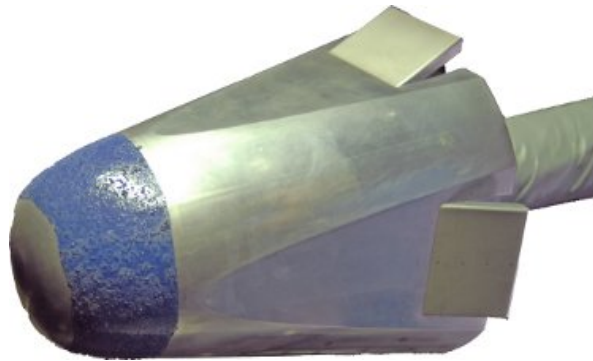
# Longshot Experiments, effects of roughness location

“Which zone of the nose is the most likely to trigger transition?”

- Smooth case
- Roughness front
- Roughness back
- Roughness everywhere

Expert model

- Laminar theoretical Stanton
- Turbulent Theoretical Stanton



Roughness [0.21 – 0.42mm] medium Reynolds number

Roughness on the front are less effective



# Longshot Experiments, effects of roughness size

- Tests with different sizes of roughness at different Reynolds numbers.

## Test matrix

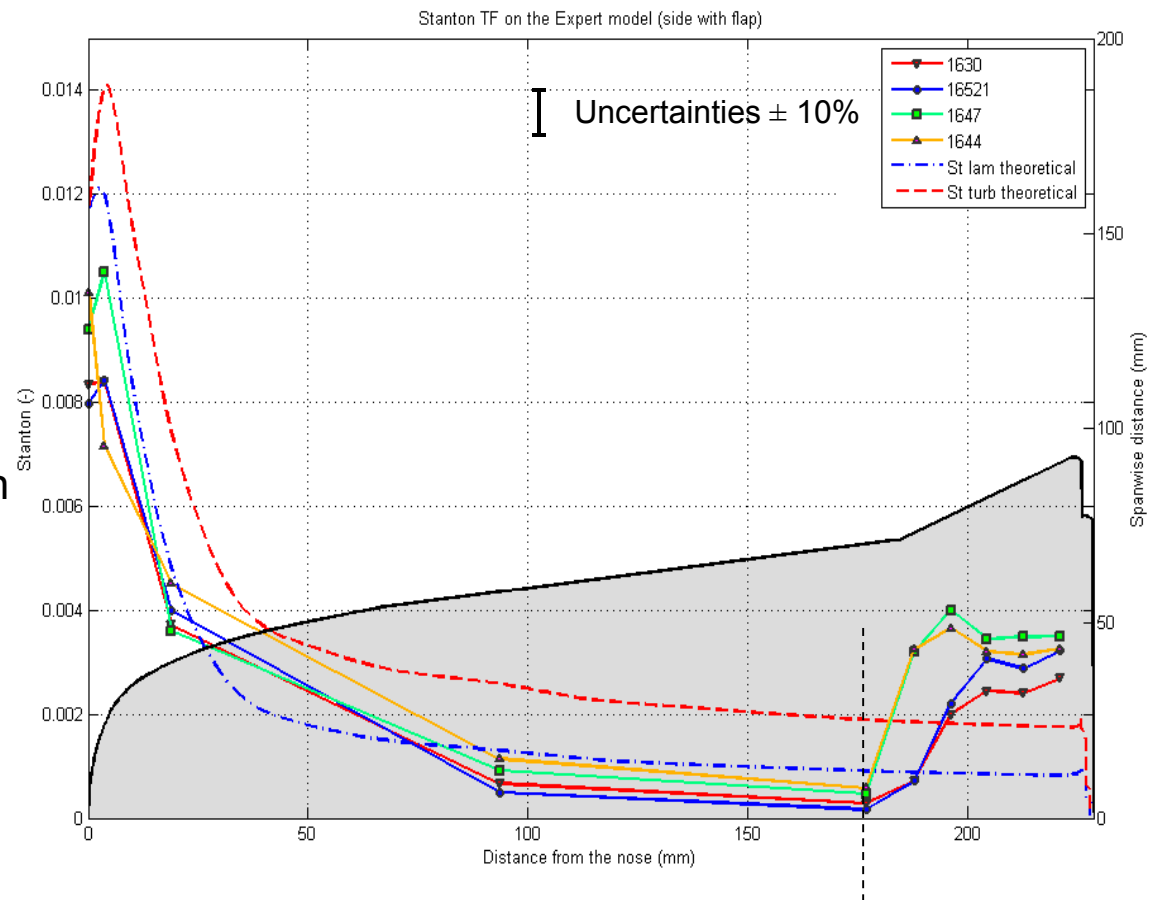
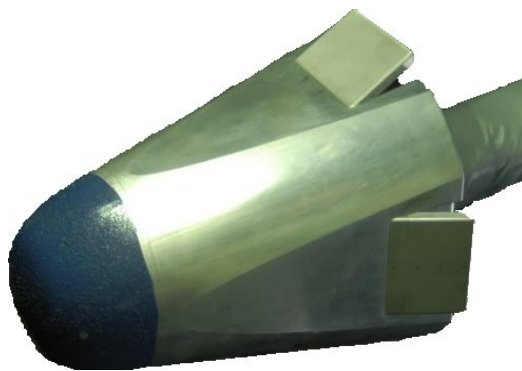
Reynolds number	$Re_L \approx 3.2 \cdot 10^6$	$Re_L \approx 1.7 \cdot 10^6$
Smooth case		
Range [0.15 – 0.2mm]		
Range [0.2 – 0.3mm]		
Range [0.21 – 0.42mm]		
Range [0.42 – 0.59mm]		



# Effects of roughness size medium Re

- Results on the flap side  $Re_L \approx 3.2 \cdot 10^6$  (medium)

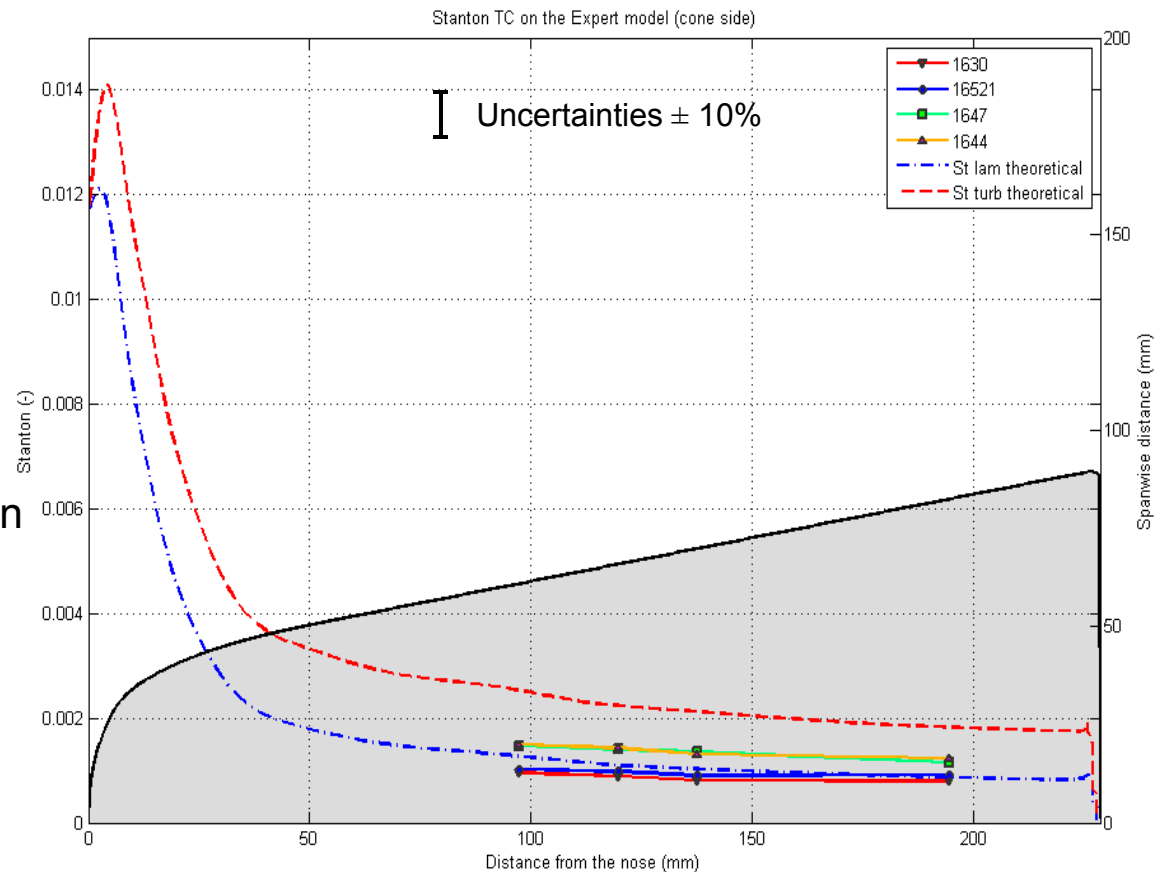
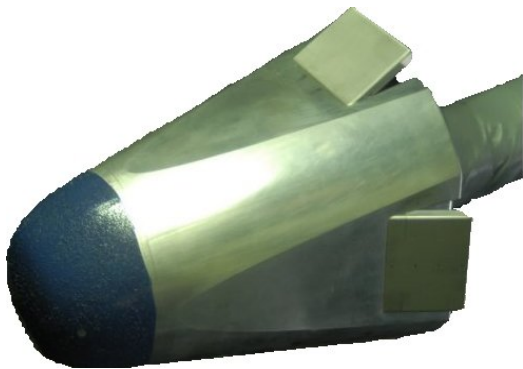
- Smooth case
- range [0.15 – 0.2]
- range [0.2 – 0.3]
- range [0.21 - 0.42]
- Expert model
- Laminar theoretical Stanton
- Turbulent Theoretical Stanton



# Effects of roughness size medium Re

- Results on the cone side  $Re_L \approx 3.2 \cdot 10^6$  (medium)

- Smooth case
- range [0.15 – 0.2]
- range [0.2 – 0.3]
- range [0.21 - 0.42]
- Expert model
- Laminar theoretical Stanton
- Turbulent Theoretical Stanton

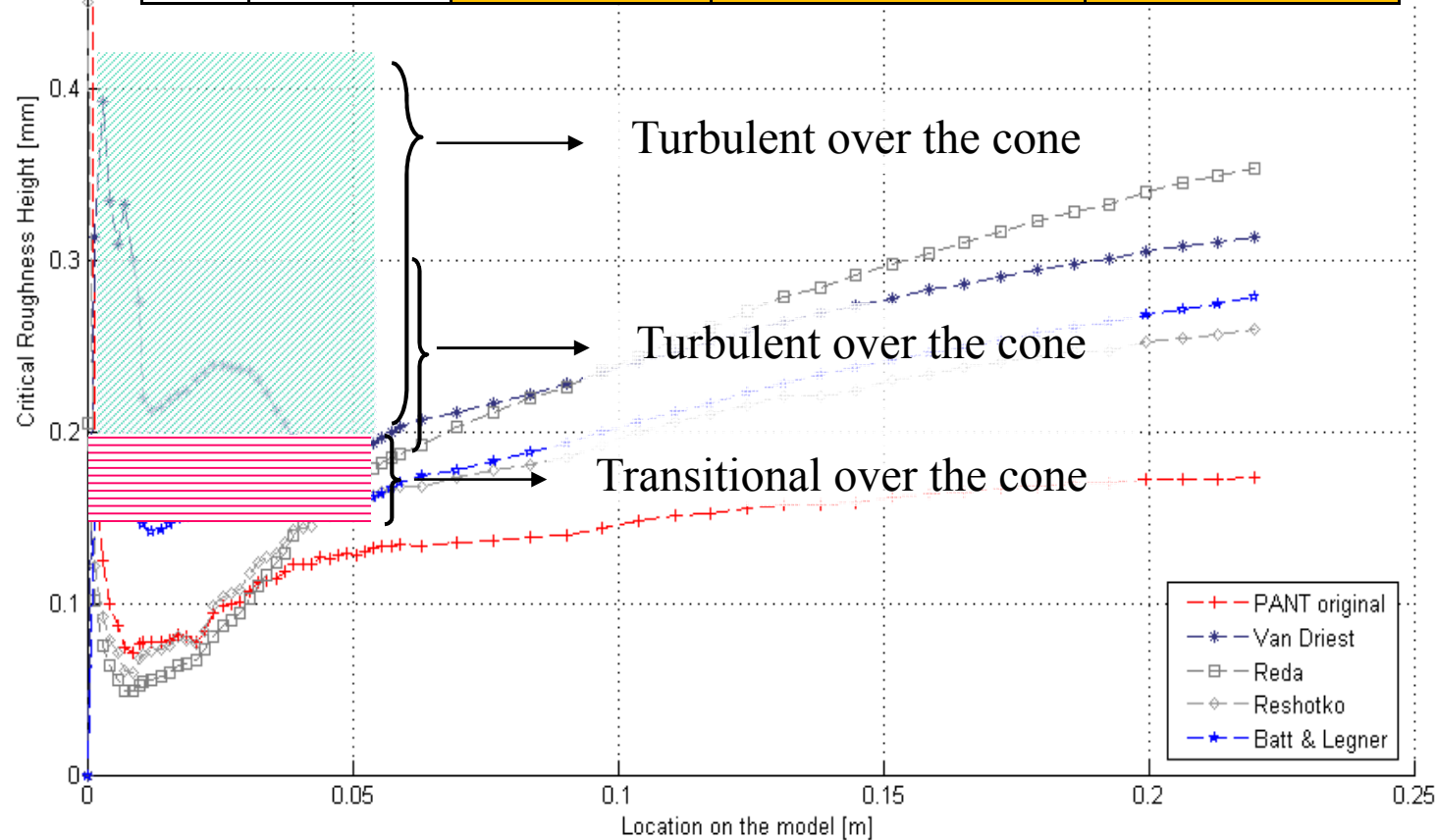


# Effects of roughness size medium Re

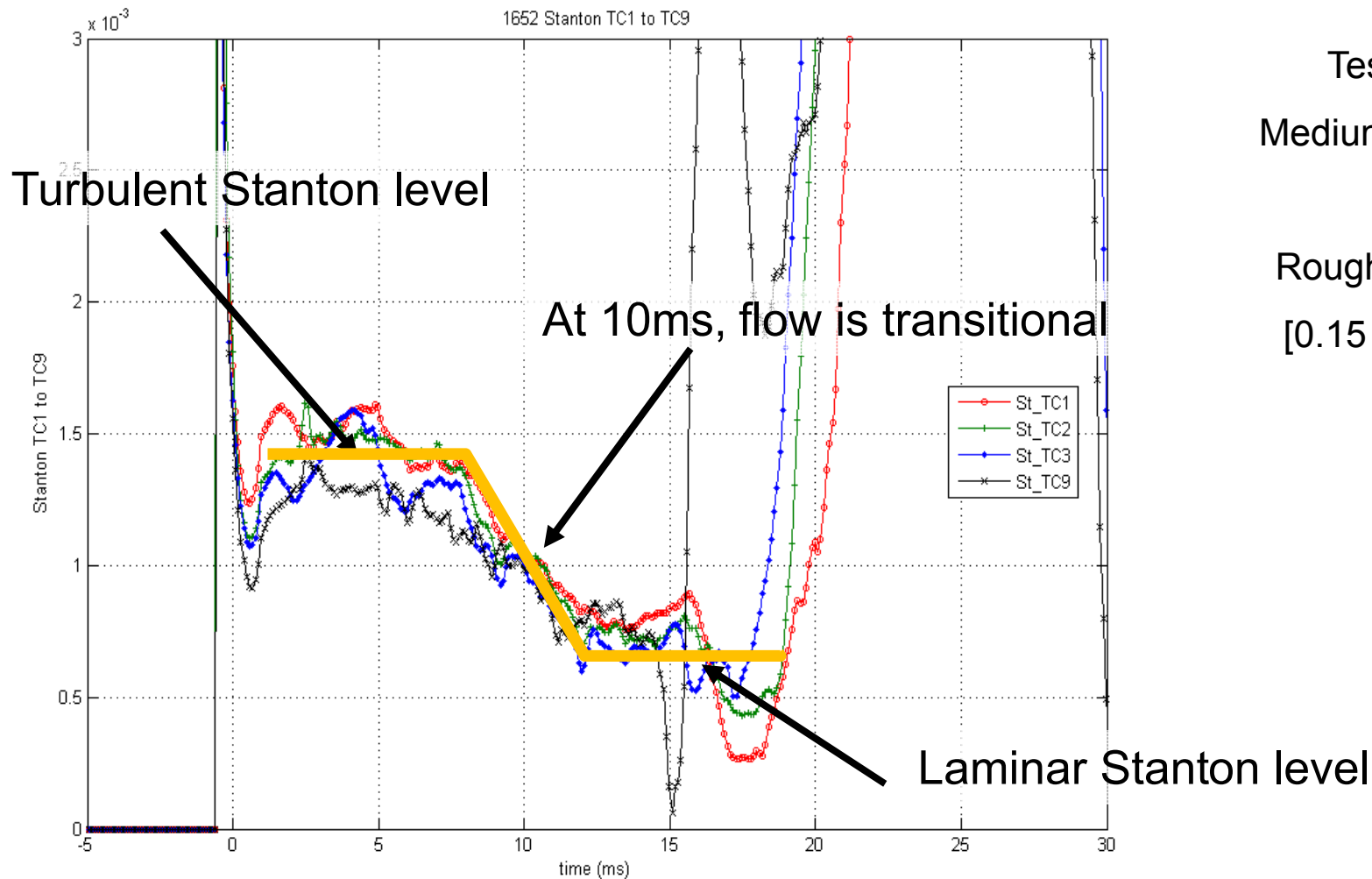
Critical heights leading to transition for Longshot med Reynolds

Medium Reynolds				
Shot	Roughness	Cone side	Flat surface on flap side	Flap on flap side
1630	Smooth	Laminar	Laminar	Transitional
1652	[0.15-0.2]	Transitional	Laminar	Transitional
1647	[0.2-0.3]	Turbulent	Transitional	Turbulent
1644	[0.21-0.42]	Turbulent	Turbulent	Turbulent

•  $Re_L \approx 3.2 \cdot 10^6$   
(medium)



# Effects of roughness size medium Re



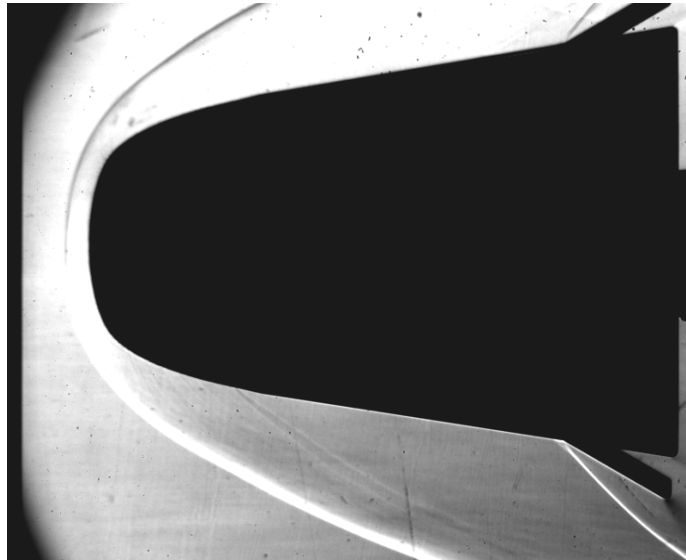
Test 1652  
Medium Reynolds

Roughness size  
[0.15 – 0.2mm]

This test will be used as reference for the roughness density effect



# Effects of roughness size medium Re



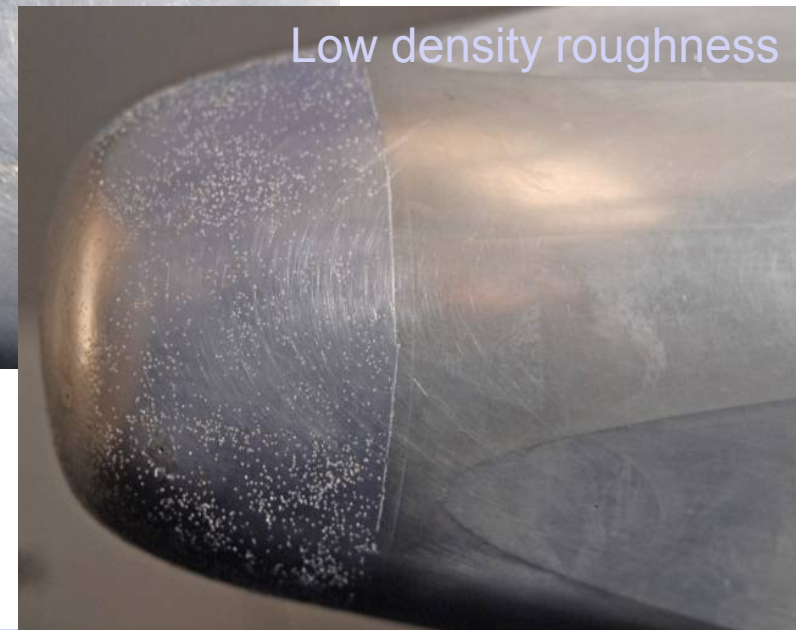
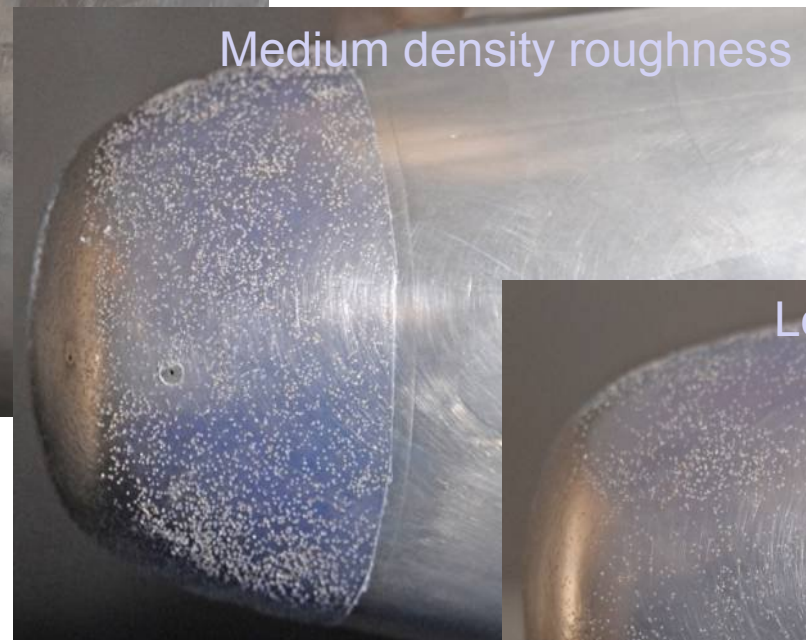
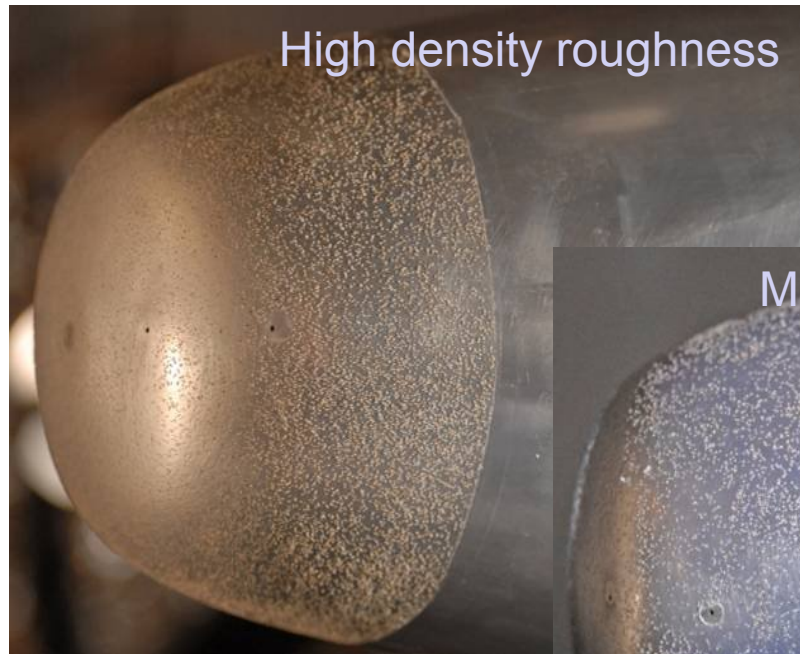
• t=4ms, turbulent flow, no recirculation

• t=10ms, transitional flow, recirculation appears

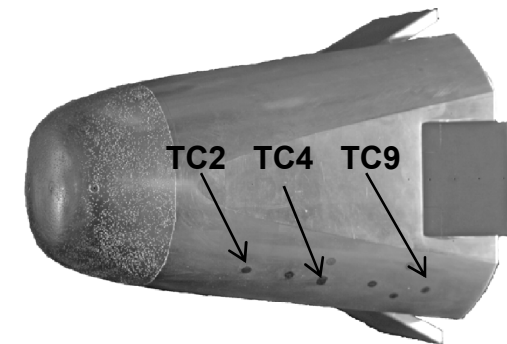
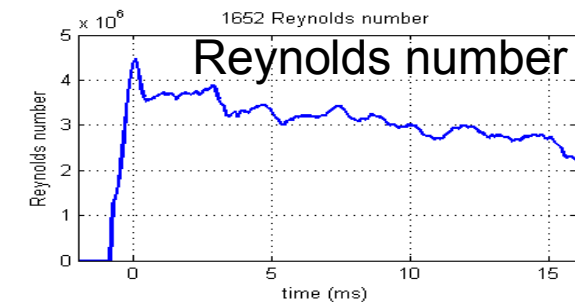
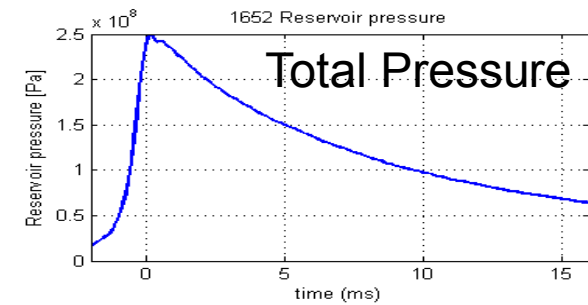
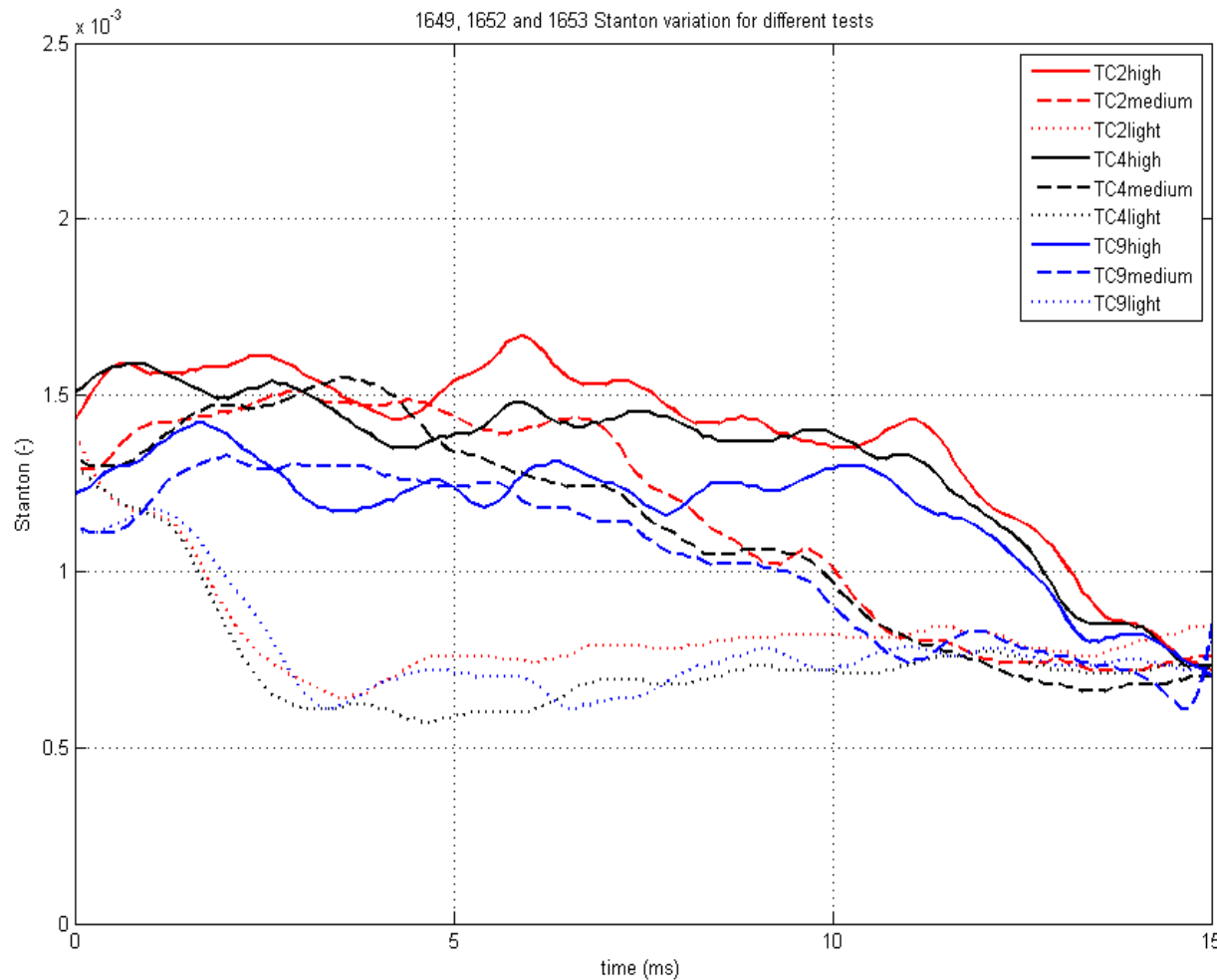
• t=12ms, laminar flow, recirculation increases



# Effects of roughness density



# Effects of roughness density



Test 1652

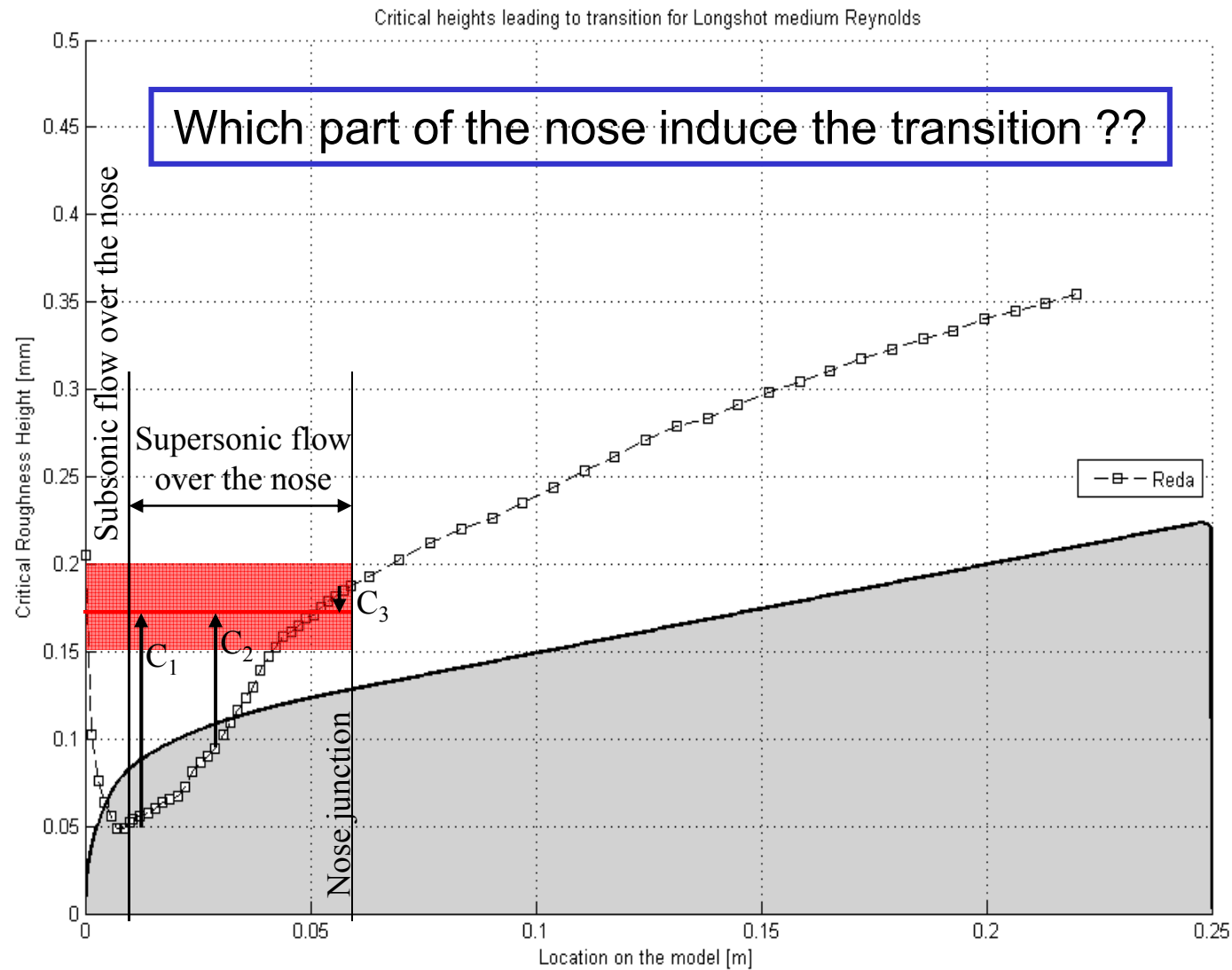
Medium Reynolds

Roughness size [0.15 – 0.2mm]



von Karman Institute for Fluid Dynamics

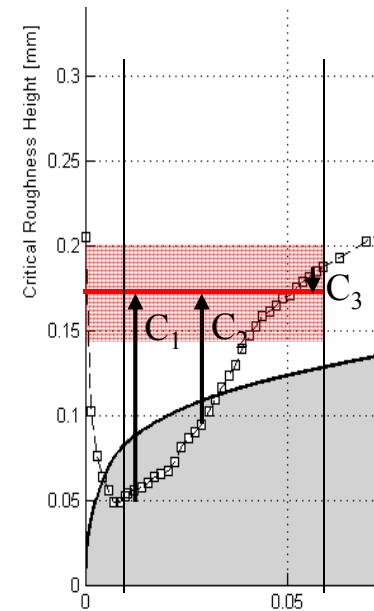
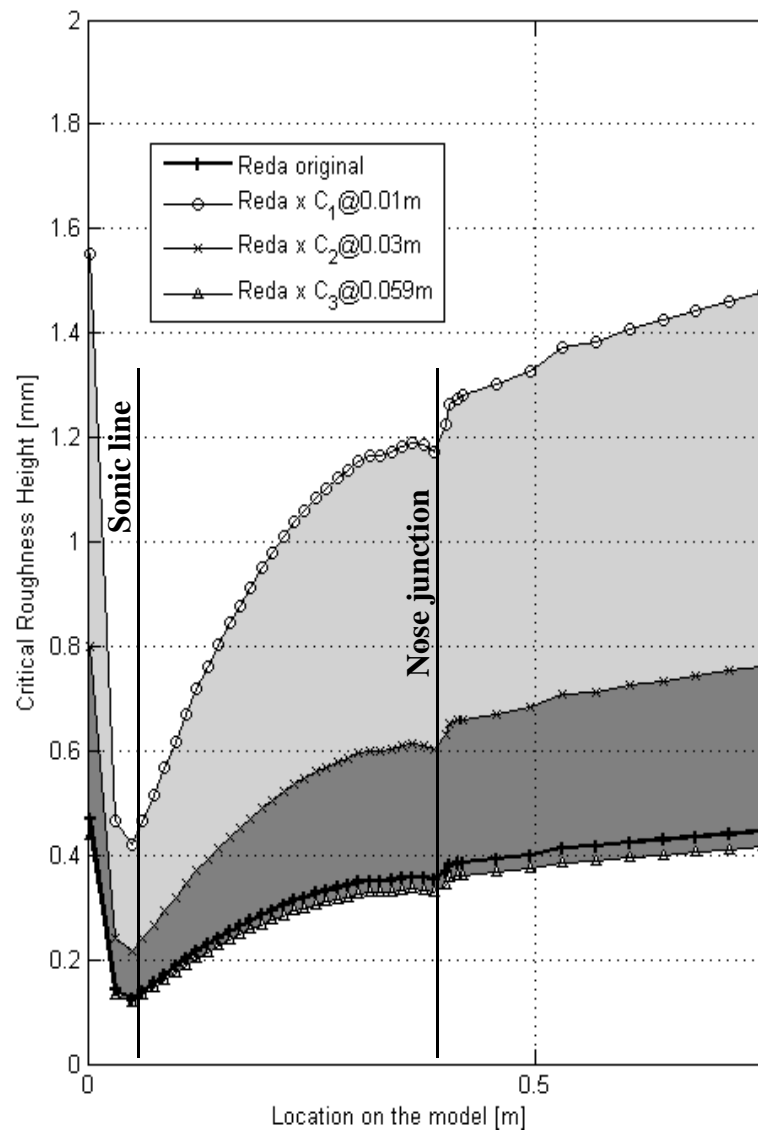
# Flight extrapolation



Medium  
Reynolds



# Flight extrapolation

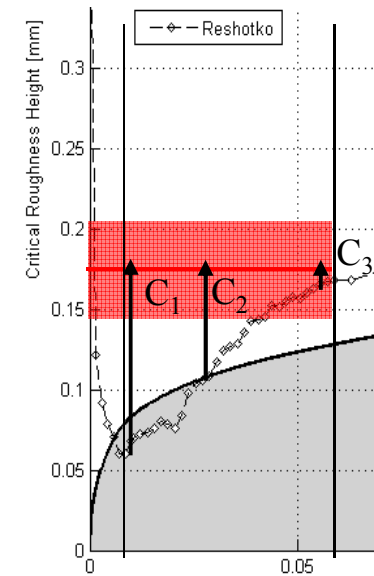
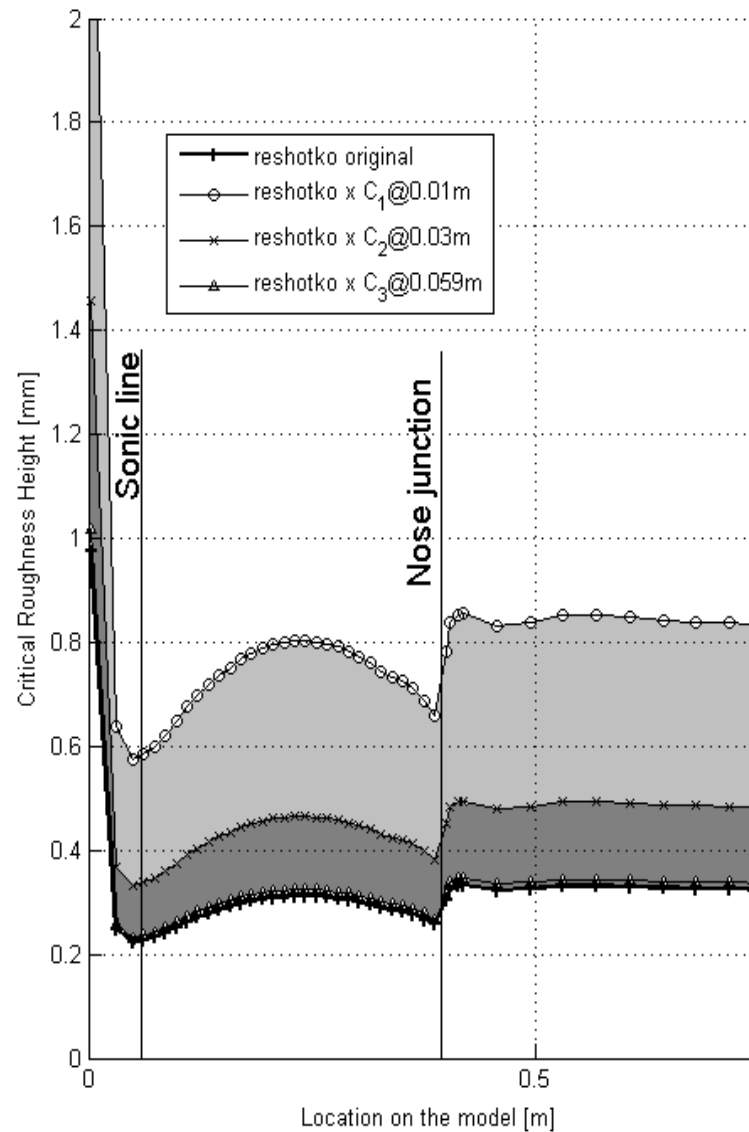


Reda flight predictions :  
0.13 - 0.37 mm

Reda prediction corrected  
by ground experiments :  
0.12 – 1.2 mm



# Flight extrapolation



Reshotko flight predictions :  
0.22 - 0.32 mm

Reshotko prediction corrected  
by ground experiments :  
0.22 – 0.8 mm



# Conclusions

- To trigger transition, the most effective part of the nose for distributed roughness is the rear part,
- For medium Reynolds number ( $Re_L \approx 3.2 \cdot 10^6$ ), transition occurs for roughness size greater than 0.175mm,
- For low Reynolds number ( $Re_L \approx 1.7 \cdot 10^6$ ), transition occurs for roughness size greater than 0.5mm,
- Transition is very sensitive to distributed roughness density.
- For flight conditions, critical heights are estimated as:
  - Between 0.12 and 1.2mm (Reda)
  - Between 0.22 and 0.8mm (Reshotko)

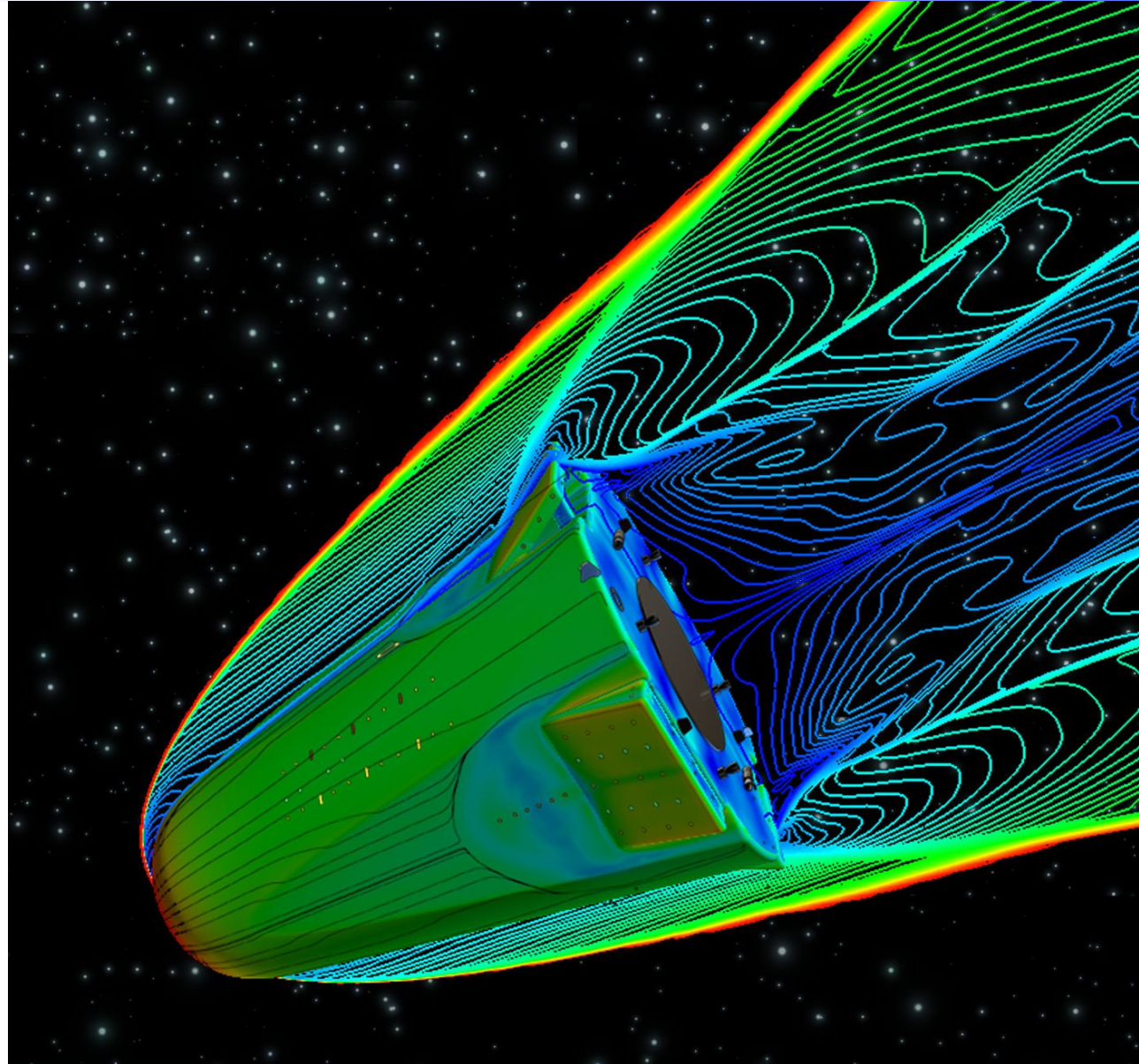


# Future work

- Main remaining unknown : Distributed roughness characteristics occurring in flight (size, location, density, shape...)
- Reduce the uncertainties of flight extrapolation with additional tests in the Longshot facility.
  - More precise height of roughness
  - Better definition of the most critical area
  - Wall temperature effect
- ..... Launch: post flight analysis should help us to choose the best criteria and the best approach for extrapolation to flight .



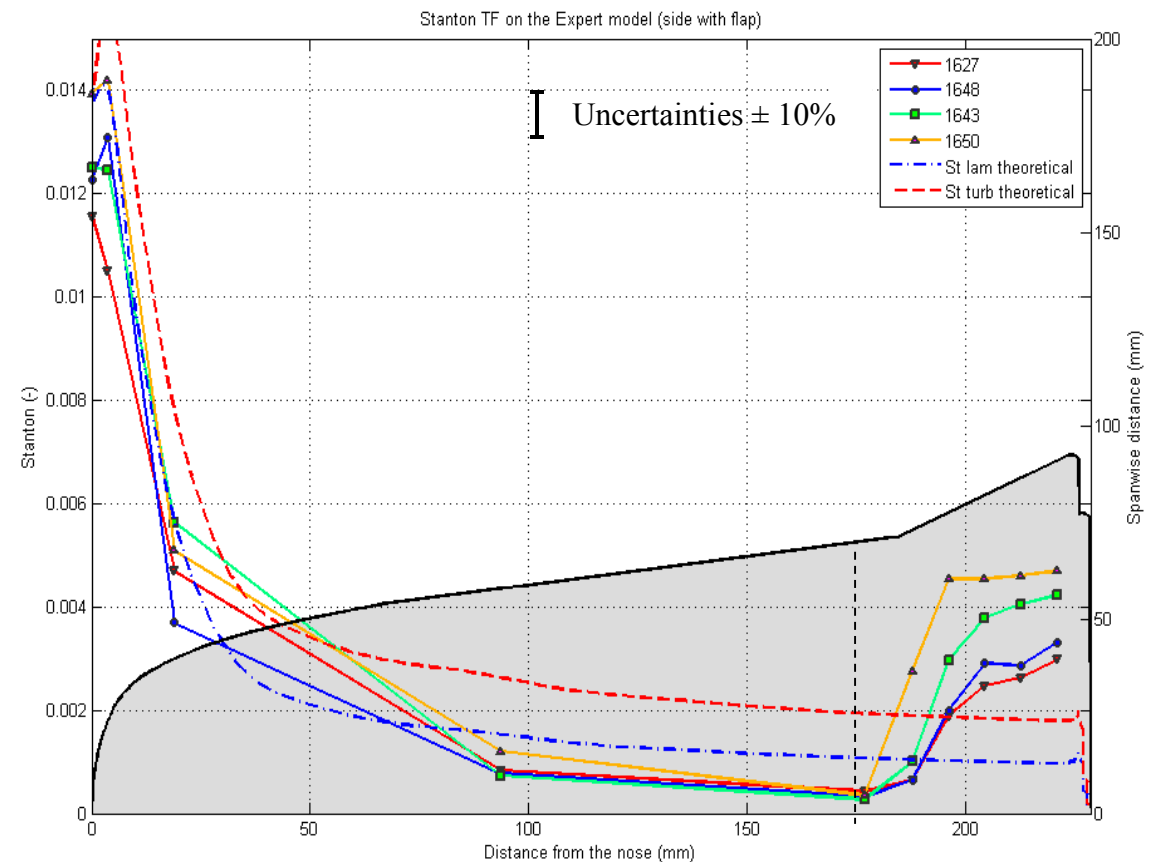
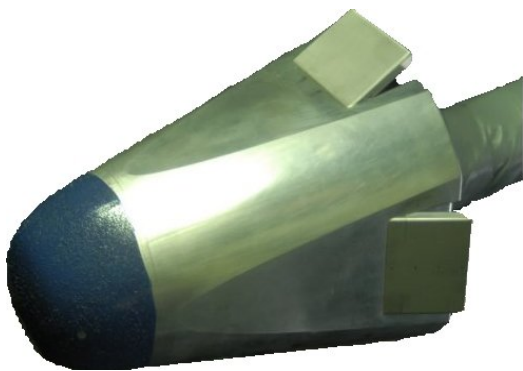
Thanks for your attention



# Longshot Experiment, effects of roughness size low Re

- Results on the flap side  $Re_L \approx 1.7 \cdot 10^6$  (low)

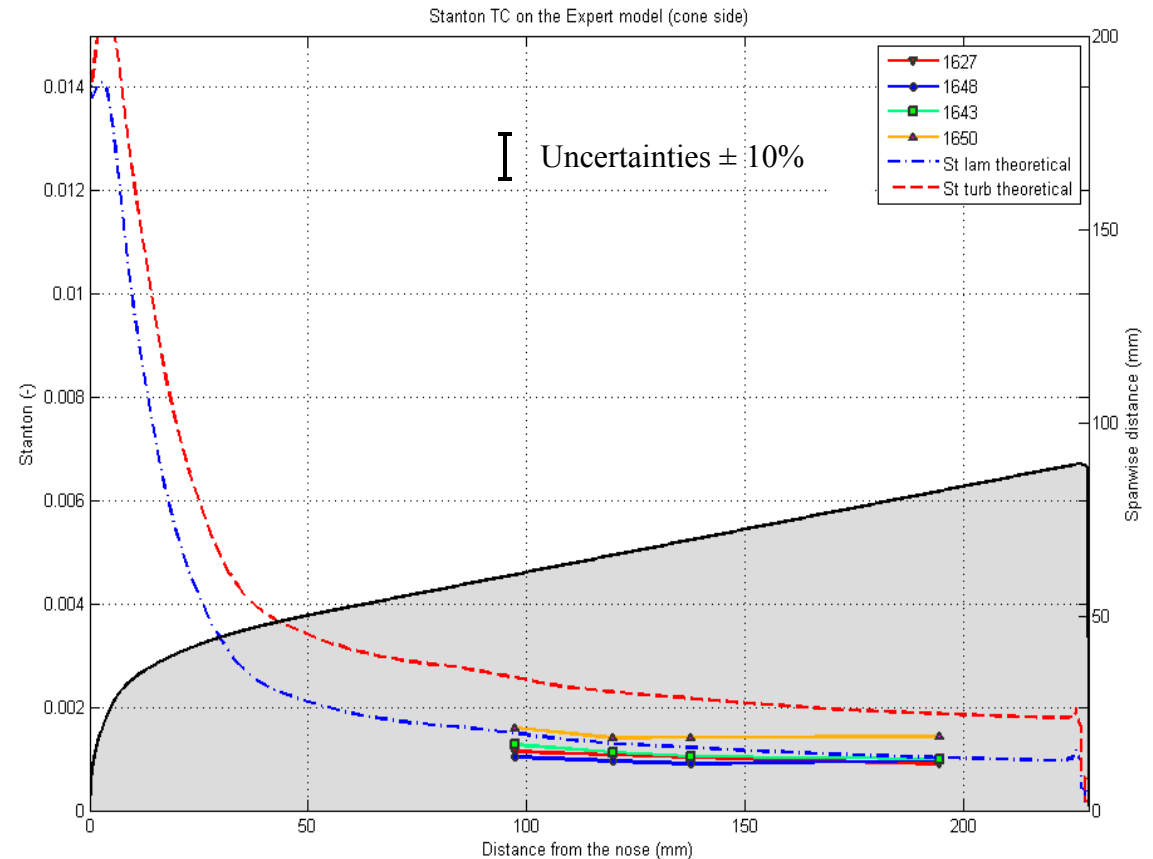
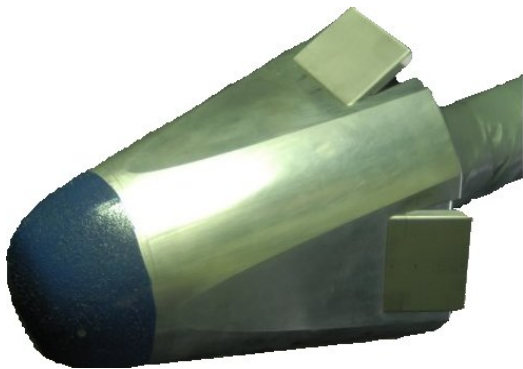
- Smooth case
- range [0.2 - 0.3]
- range [0.21 - 0.42]
- range [0.42 - 0.59]
- Expert model
- Laminar theoretical Stanton
- Turbulent Theoretical Stanton



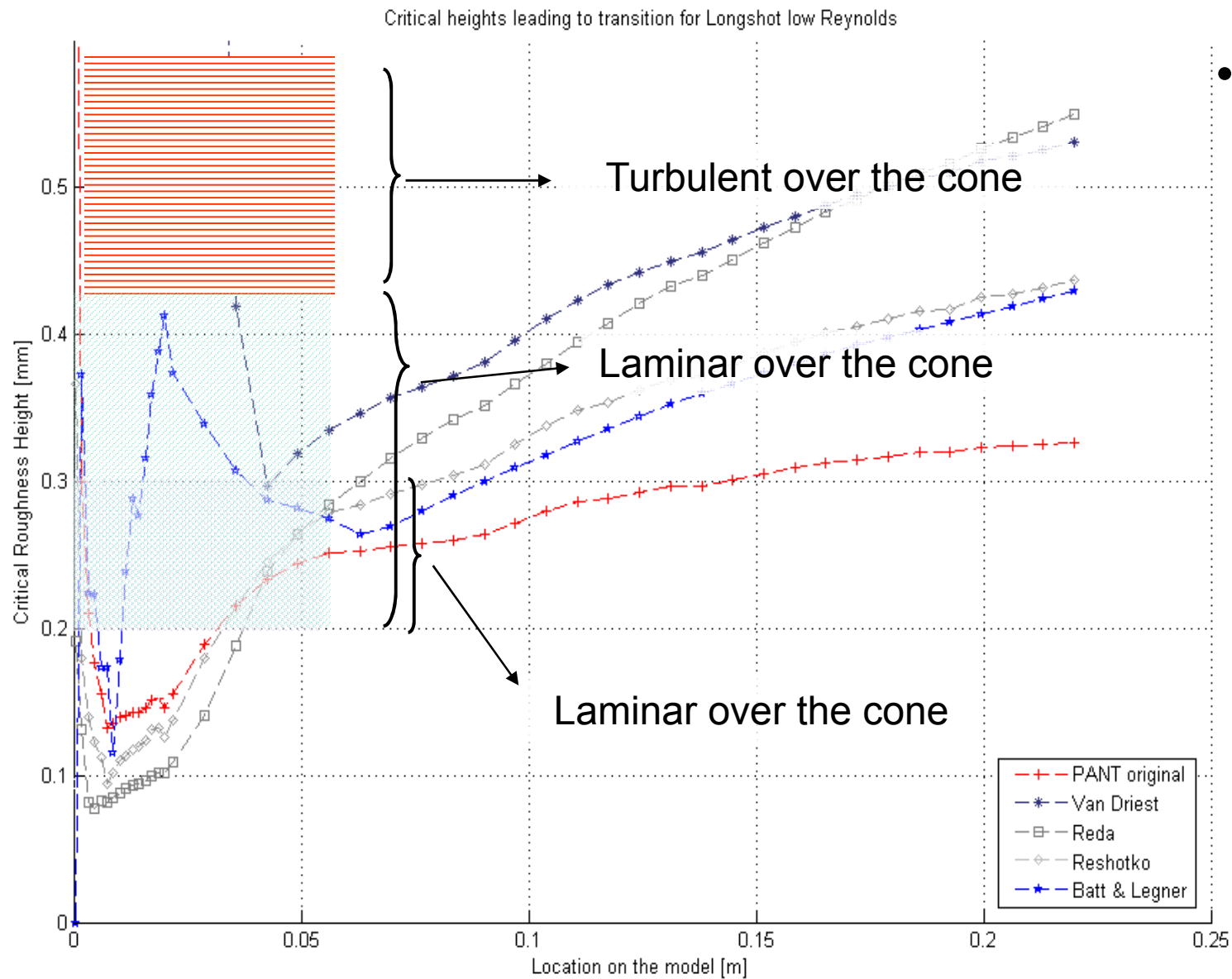
# Longshot Experiment, effects of roughness size low Re

- Results on the cone side  $Re_L \approx 1.7 \cdot 10^6$  (low)

- Smooth case
- range [0.2 - 0.3]
- range [0.21 - 0.42]
- range [0.42 - 0.59]
- Expert model
- Laminar theoretical Stanton
- Turbulent Theoretical Stanton



# Longshot Experiment, effects of roughness size low Re



# Empirical correlations used

- Reda  $\left[ \frac{\rho_k u_k k}{\mu_w} \right]_{\text{TR}} = \text{const} \tan t$
- Reshotko  $\text{Re}_{\theta, \text{TR}} = 180 \left( \frac{k}{\theta} \right)^{-1} \left( \frac{T_e}{2T_w} \right)^{-1.27}$



# Empirical correlations used

- PANT original

$$\text{Re}_{\theta, \text{TR}} = 215 \left( \frac{k T_e}{\theta T_w} \right)^{-0.7}$$

- Van Driest

$$\text{Re}_{\theta, \text{TR}} = 200 \left( 1 + 0.9 \left( \frac{T_w}{T_e} - 1 \right) + 0.048 \times M_e^2 \right) \times \frac{\theta}{k} \times \left( 1 + \frac{350 \times k}{R_N} \right)$$

- Batt & Legner

$$\text{Re}_{\theta, \text{TR}} = \frac{500}{\psi^{1.5}} \quad \psi = \frac{k}{\theta} \times \frac{T_e}{T_w} \times \left( \frac{1}{1 + \frac{350 \times k}{R_N}} \right)$$



# Similarity parameter $T_w/T_\infty$

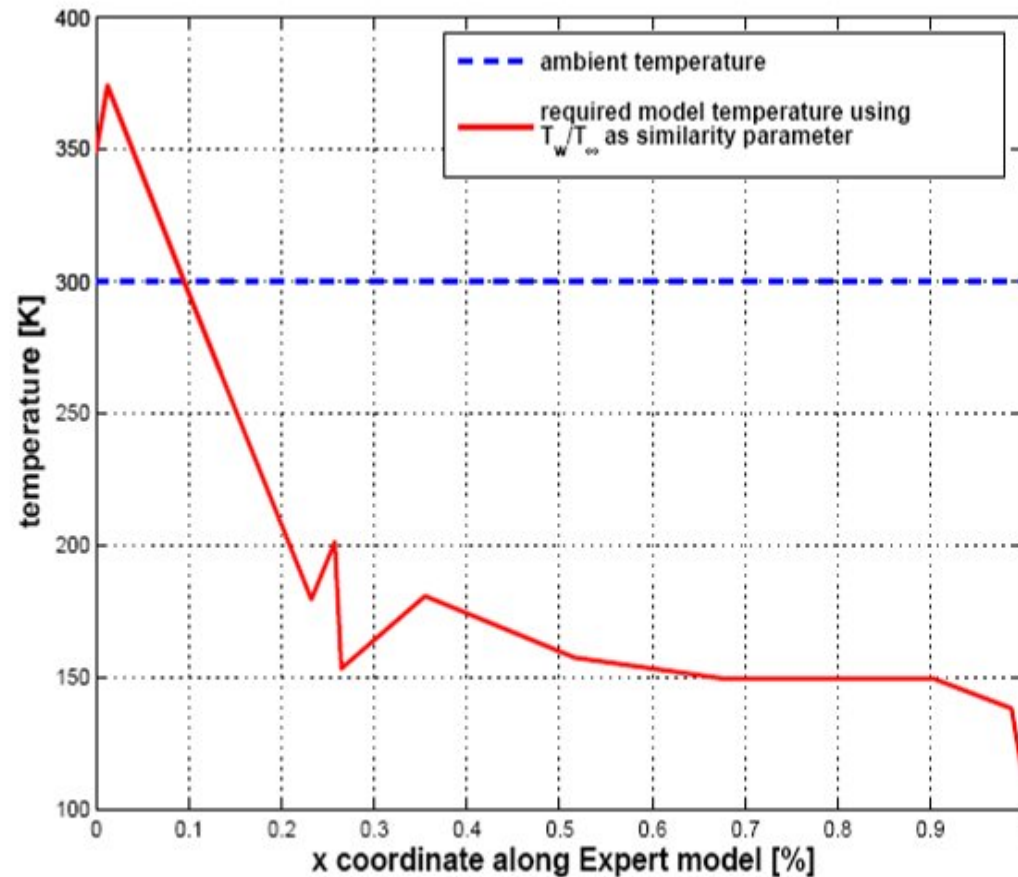
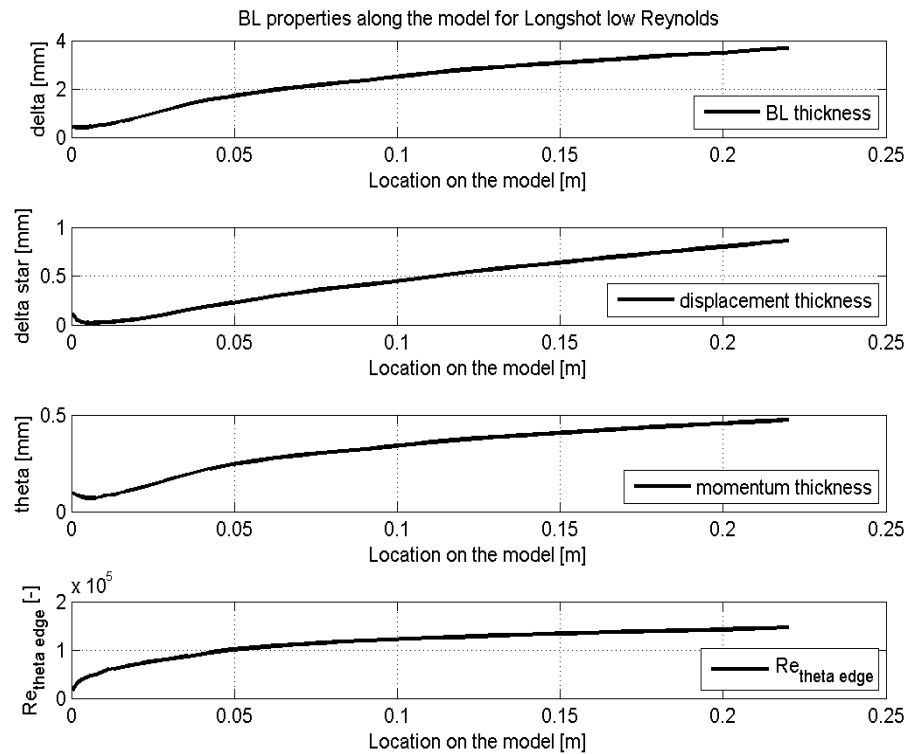
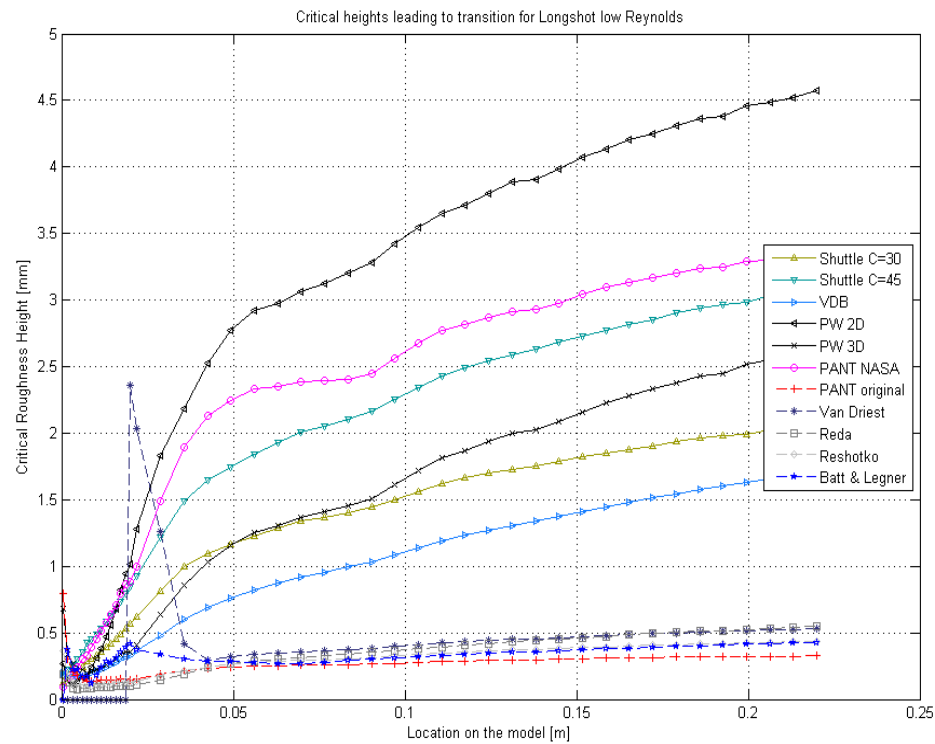


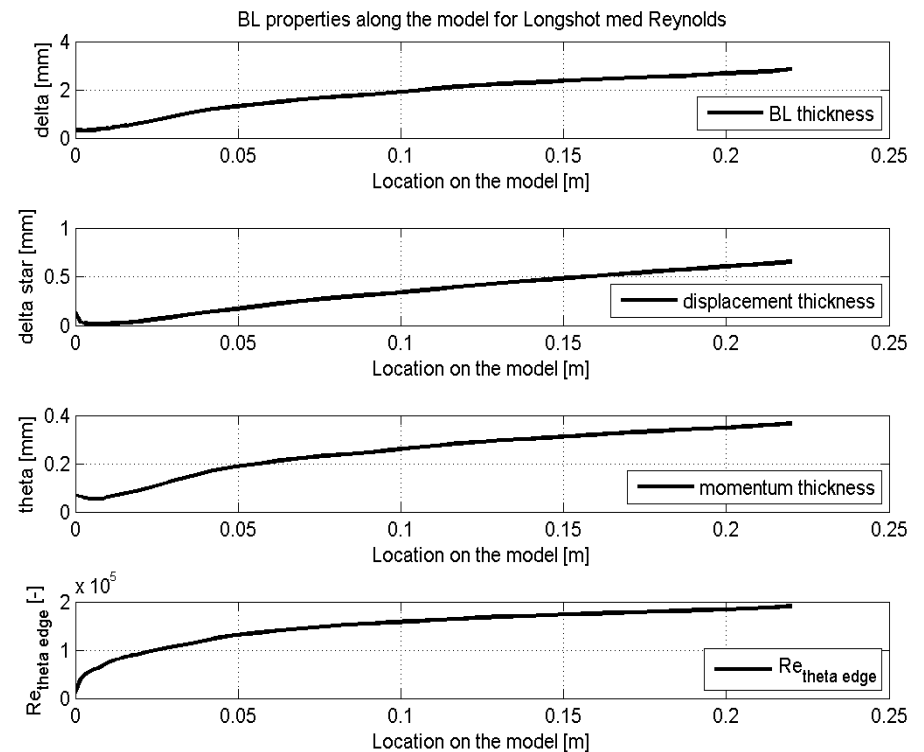
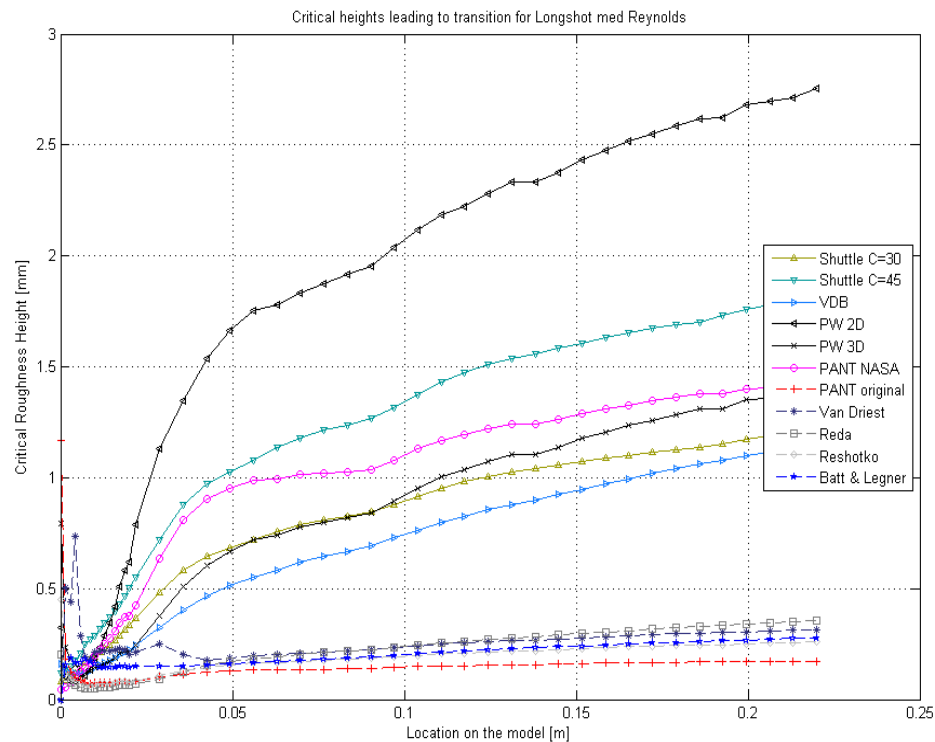
Figure 12: Required surface temperature along the Expert model to fulfill the similarity parameter  $T_w/T_\infty$



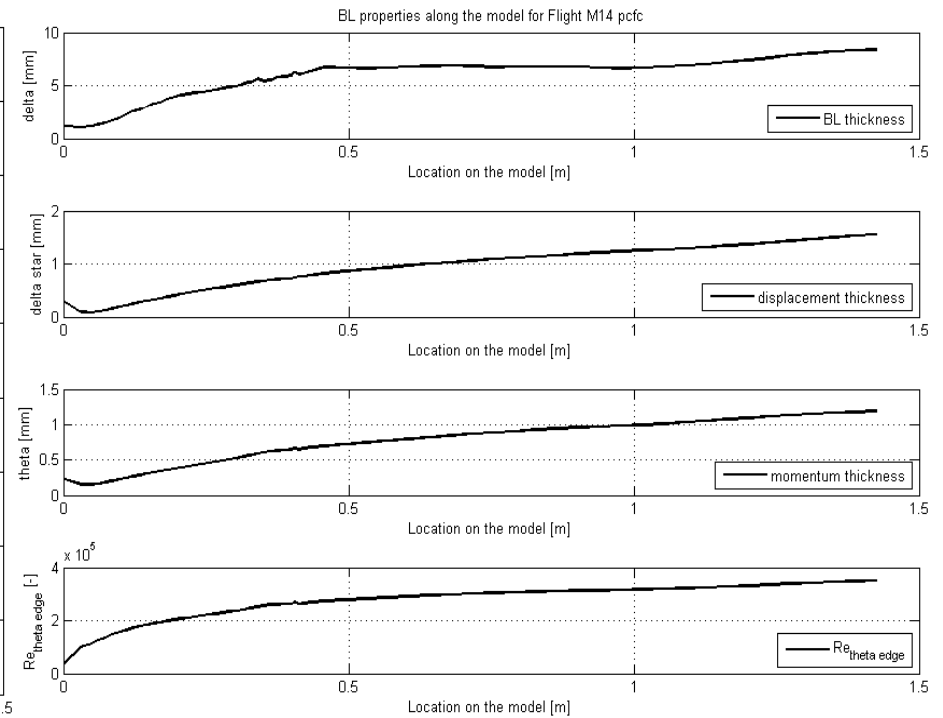
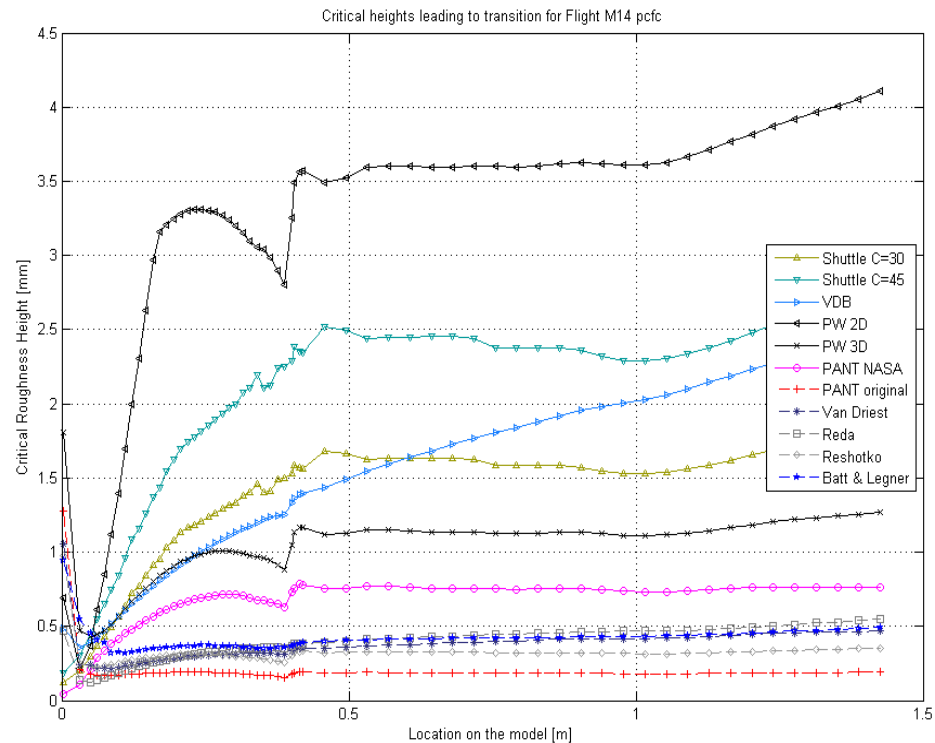
# CFD Longshot low Reynolds



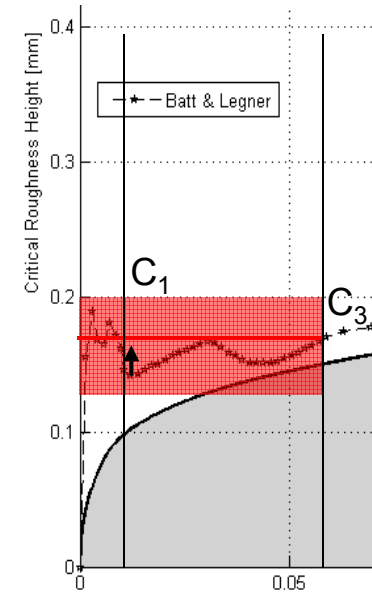
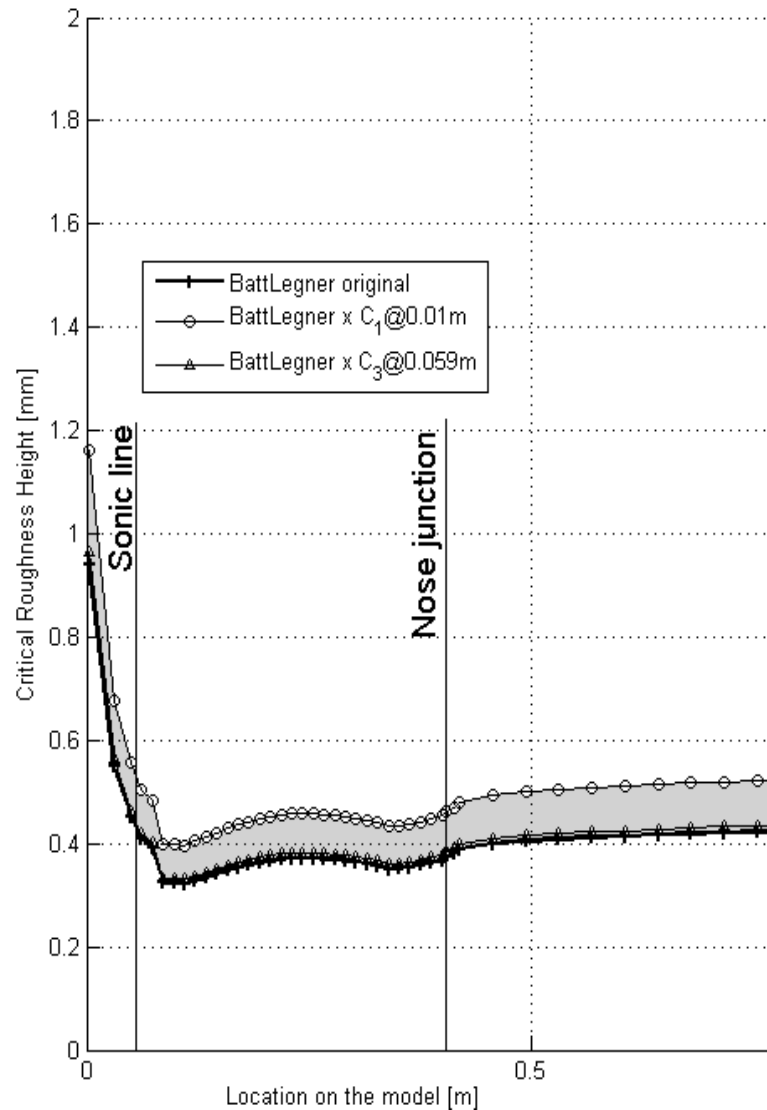
# CFD Longshot medium Reynolds



# CFD Flight M14 pcfc



# Flight extrapolation



Uncertainties in  
correlation  
computation

Batt & Legner flight predictions

:  
0.32 - 0.41 mm

Batt & Legner prediction  
corrected

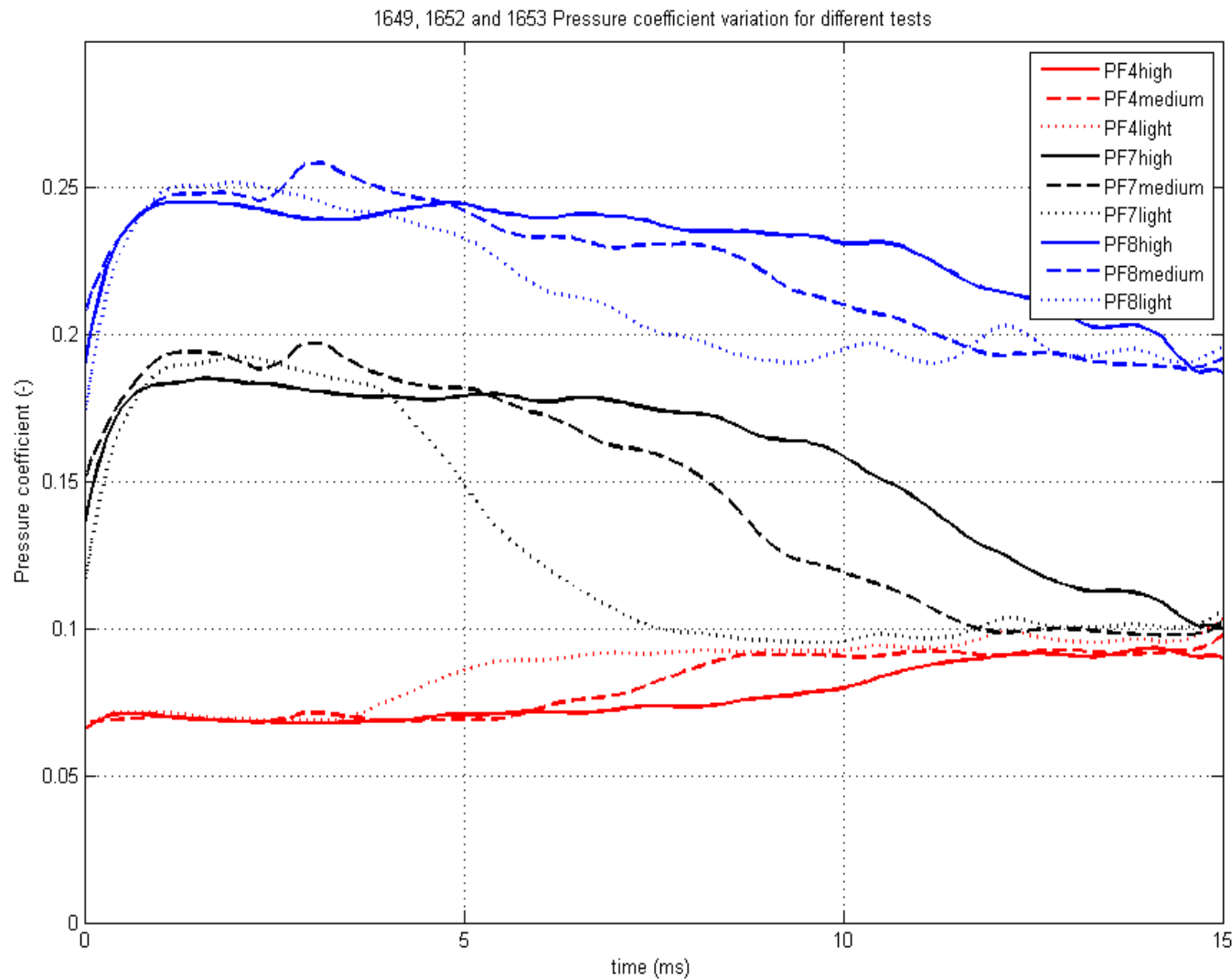
by ground experiments :

0.32 - 0.51 mm



von Karman Institute for Fluid Dynamics

# Pressure measurements



Test 1652

Medium Reynolds

Roughness size  
[0.15 – 0.2mm]

